Geophysical and botanical monitoring of simulated graves in a tropical rainforest, Colombia, South America.

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Abstract

In most Latin American countries there are significant numbers of missing people and forced disappearances, currently ~74,000 only in Colombia. Successful detection of shallow buried human remains by forensic search teams is currently difficult in varying terrain and climates. Within this research we built four simulated clandestine burial styles in tropical rainforests, as this is a common scenario and depositional environment encountered in Latin America, to gain knowledge of optimum forensic geophysics detection techniques. The results of geophysically monitoring these burials using ground penetrating radar, magnetic susceptibility, bulk ground conductivity and electrical resistivity are presented from one to forty three weeks post-burial. Radar survey results with both the 250 MHz and 500 MHz frequency antennae showed good detection of modern simulated burials on 2D profiles and horizontal time slices but poor detection on the other simulated graves. Magnetic susceptibility, bulk ground conductivity and electrical resistivity results weregenerally poor at detecting the simulated targets. Observations of botanical variations on the test site show rapid regrowth of *Malvaceae* and *Petiveria alliacea* vegetation over all burials that are common in these forests, which can make detection more difficult.

Key words: Forensic geophysics, clandestine grave, ground penetrating radar, magnetic susceptibilty, conductivity, resistivity

Research Highlights

- Thousands of people currently missing in Latin America that may be buried.
- This study created simulated clandestine graves and monitored for 43 weeks.
- GPR optimal detection technique but caution on historic graves.
- Botanical results show rapid forest vegetation re-growth over burials

1. Introduction

In many South American countries there are significant numbers of people missing and those who have been subjected to forced disappearances (www.desaparecidos.org). For example, in Colombia there are currently ~74,000 people missing, of which it has been estimated that ~21,000 are forced disappearances (www.medicinalegal.gov.co). Discovered clandestine graves of victims have been reported to be isolated (Solla and Iscan, 2001; Iscan and Solla, 2005), co-mingled and mass burials (Varas and Leiva, 2012), and in a variety of burial styles, depths below ground level and depositional environments (Solla and Iscan, 2001; Iscan and Solla, 2005; Varas and Leiva, 2012). Such numbers of victims has been reported elsewhere globally, for example, in 19th Century Irish mass burials (Ruffell et al., 2009), USA race riot victims (Witten et al., 2000), Spanish Civil War mass burials (Rioz et al., 2010, Rioz et al., 2012, Fernandez et al., 2016), World War Two burials (Fiedler et al., 2009, Ossokoswki, 2013), in post-WW2 Polish repression mass burials (Szleszkowski et al., 2014), the Northern Ireland 'Troubles' mostly isolated burials (www.iclvr.ie), the 1990s Balkan wars mass burials (Brown, 2006), and sadly in active civil wars with both isolated and mass burials (www.syriahr.com).

Current forensic search methods to detect both isolated and mass clandestine burials of murder victims are highly varied and have been reviewed elsewhere (Pringle et al., 2012a; Parker et al., 2010), with best practice suggesting a phased approach, moving from large-scale remote sensing methods (Kalacska et al., 2009) down to initial ground reconnaissance (Ruffell and McKinley, 2014) and control studies before full searches are initiated (Harrison and Donnelly; 2009; Larson et al., 2011). These full searches have also involved a variety of methods, including forensic geomorphology (Ruffell and McKinley, 2014), forensic botany (Aquila et al., 2014) and entomology (Amendt, 2007), scent-trained search dogs (Lasseter et al., 2003;), physical probing (Ruffell, 2005a;), thanatochemistry (Vass et al., 2008;) and near-surface geophysics (France et al., 1992; Nobes, 2000; Ruffell, 2005b; Pringle and Jervis, 2010a; Novo, 2011).

Recent forensic geophysical research using simulated clandestine graves have found optimal detection methods and configurations are highly variable, depending upon a host of factors, the most important deemed to be time since burial, burial style, local soil type, vegetation and climate (France et al., 1992; Pringle et al., 2008; Jervis et al., 2009; Schultz and Martin, 2011; Pringle et al., 2012a; Schultz and Martin, 2012; Pringle et al., 2012b; Ruffell et al., 2014; Pringle et al., 2015a,b; Pringle et al., 2016). As reported in Molina et al. (2015) and Molina et al. (2016), there has been little research to-date in South America using controlled test experiments to determine optimal geophysical search technique(s) and equipment configuration(s). This is critical as South America will have different burial conditions to other controlled work, including soil types, climate and vegetation, which will affect geophysical detection.

Ground penetrating radar (GPR) is one of the most popularly-used geophysical equipment in the search for evidence buried in the ground by judicial authorities technical and police worldwide (Pringle et al., 2012a). GPR has been successful in numerous controlled experiments (France, 1992; Pringle et al., 2008; Jervis et al., 2009; Schultz and Martin, 2011; Pringle et al., 2012a; Schultz and Martin, 2012; Pringle et al., 2012b; Ruffell et al., 2014; Molina et al., 2015; Pringle et al., 2016;), and criminal cases (Ruffell, 2005b; Pringle et al., 2008; Ruffell et al., 2014), but it has been suggested that in some cases it has been used based on past successes and without consideration of local depositional conditions (Jervis et al., 2009). GPR has not been successful in locating graves in all conditions (Rioz, 2010), in saline soils (Pringle et al., 2012b) rich in wet clay (Pringle and Jervis, 2010a) or drawbacks in its implementation (Pringle et al., 2012c).

Magnetic susceptibility (ms) is an emerging forensic field technique. It works by passively measuring a sample or sample area in SI dimensionless units, the causes of which are complex (see Pringle et al., 2015b for background). The ms reading usually comprises a bulk value of the material present within the measured area; thus values are usually high when multiple magnetic minerals such as magnetite and ferromagnetic materials made by man, amongst others are present (Miller, 1996). The use of magnetic susceptibility for forensic purposes has been successful both in several simulated environments and with different buried targets (Milsom and Eriksen, 2011; Linford, 2004), Pringle et al., 2015b;), to differentiate soil samples (Guedes et al., 2013), and to identify illegal dumped waste (Manrong et al., 2009), but is seldom used in forensic investigations.

Bulk ground conductivity Electro-Magnetic (EM) surveys are a quick active field technique to measure relative changes in ground conductivity between targets and background readings. The Slingram method works by inducing a primary electro-magnetic field in a transmitter coil and measuring any secondary ones produced from any conductive objects in a receiver coil, the instrument being sequentially moved between sample positions with the coils at a constant separation (see Reynolds, 2011; Thiesson et al, 2011 for background). Both EM fields can be measured, with targets detected as relatively high/low anomalies, compared to background values, depending if ferrous or non-ferrous materials are present (Pringle et al., 2012a). Although more widely used in environmental forensics (Reynolds, 2011) it has had mixed results in criminal searches (Nobes, 2000; Pringle et al., 2012a; Bigman, 2012), in controlled studies depositional environment is deemed very important, it was found to be problematic in urban environments (Pringle et al., 2008; Dick et al., 2015). Decompositional fluids have also been found to be temporally variable but could be detectable with this method (Pringle et al., 2015a). Electrical resistivity is the reciprocal of conductivity and has been widely used in environmental forensics (Reynolds, 2011), detection of clandestine graves (Pringle and Jervis, 2010a), ancient burials (Dick et al., 2015;) and in controlled experiments (France et al., 1992; Pringle et al., 2008; Jervis et al., 2009; Pringle et al., 2012b; Pringle et al., 2012c;); however major depositional environment variables can affect target detection, including soil moisture (Jervis and Pringle, 2014;) soil type (Pringle et al., 2012a;) and salinity (Pringle et al., 2012b).

The Molina et al. (2015) and Molina et al. (2016) papers report on geophysical monitoring results of simulated clandestine and historic burials in a rural depositional environment in Colombia. This paper provides a critical comparison of this study, also using simulated clandestine graves but in a tropical rainforest depositional environment in Colombia that is sadly an all too common burial discovery scenario in Latin America. The research aims were: *firstly*, to assess whether radar, surface magnetic susceptibility, bulk ground conductivity and electrical resistivity methods could detect the simulated graves, *secondly*, to determine if there was an optimal time for surveying post-burial and *thirdly*, to compare results to other studies, particularly other Latin American control burial studies.

2. Material and Methods

2.1 Study site

The research site is located in a semi-rural area of the Experimental Farm Barcelona of the Los Llanos University, Colombia ~ 100 km east of the capital Bogota (Fig. 1a). The study site is in a semi-rural tropical densely vegetated environment that is typical of those encountered away from coastal areas in Colombia (Fig. 1b). The site is situated ~ 391 m above sea level. Geologically the site is underlain by alluvial rocks of Holocene age. The local soil type is a 50 cm thick sandy entisol composed of light brown alluvial sediments of fine grain size and isolated rock fragments.

The nearby University meteorological weather observation station was situated ~0.5 km from the test site, which continually recorded rainfall and temperature data. The site has an average temperature of 26 ºC and annual rainfall averages of 3,000 mm per year, with a dry period from December to March and a rainy period from April to November (IGAC, 2004). Climate data over the study period is shown in Figure 2.

Fig. 1 & new Fig. 2 position.

2.2 Simulated graves

It was decided to use freshly dispatched domestic pig cadavers to simulate clandestine graves of murder victims as they are commonly used in such monitoring experiments (Jervis et al., 2009; Schultz & Martin 2011/2012; Pringle et al., 2015a; Pringle et al., 2016; Molina et al., 2015), comprising similar chemical compositions, body size, tissue: body fat ratios and skin/hair types to humans (Pringle et al., 2016). The National Charter for the Protection of Animals (1989) covers biomedical use of animals in Colombia (Ministry of Health, 1993). As per Molina et al. (2015), for this study it was also able to use human remains using Resolution 8430 of the Colomobian Ministry of Health Act (1993). Donated skeletonised remains were used to represent historic clandestine graves after a historical archaeological rescue by the Colombian Association of Forensic Anthropology (ACAF), as the time frame that modern human remains would take to skeletonise would be too long, typically years post-burial. The National University of Colombia Faculty of Science ethics committee had also approved the project.

Four simulated clandestine graves were excavated on 23rd October 2014 (see Table 1 and Fig. 3). For each grave, the overlying vegetation was removed and c. 1.7 m x 0.7 m holes were dug in a regular pattern (Fig. 3a). All graves were dug to ~0.5 m below ground level (bgl), this depth is commonly encountered in discovered clandestine graves in Colombia (Molina et al., 2015). One simulated grave (Pig) had a humanely dispatched (electrocuted and bled >6h before burial) ~70 kg domestic pig carcass procured from a local butcher emplaced in the centre, with it having its lower half wrapped with cloth as discovery of half-naked remain are a common burial scenario in Colombia (www.fiscalia.gov.co). A further grave (Cont) was empty acted as control and was refilled by the excavated soil. The next grave (Skel) contained the simulated historic donated skeletonised human remains and the last (Burnt) contained simulated historic donated beheaded and burnt skeletonised human remains, together with with various small arms shell casings as these were also common in Colombia (www.centrodemememoriahistorica.gov.co). These were deliberately the same as those reported in Molina et al. (2015) and Molina et al. (2016) for comparison purposes. All graves were then refilled with excavated soil back to ground level.

Fig. 2. Position.

Table 1. Position.

2.3 Ground penetrating radar data collection and processing

Repeated 250 MHz and 500 MHz frequency GPR survey datasets were collected within the survey area (Fig. 3) at *c.* 1-monthly intervals after burial (Table 2) by a Mala™ model ProEx. The 2 m x 11 m survey grid was GPR surveyed on both north-south and west-east oriented, 0.25 m spaced, parallel survey lines with 0.02 m radar trace spacings throughout using a 30 ns time window.

Once the 2D GPR profiles were acquired by the Mala RadExplorer™ data collection software, they were downloaded and imported into GSSI's RADAN v6.6 data processing software. For each profile, standard sequential processing steps were undertaken as in Molina et al. (2015) to optimize image quality. There were; (i) DC removal; (ii) time-zero adjustment to make all traces consistent, this adjustment eliminates the time zero; (iii) deconvolution; (iv) bandpass filtering to reduce noise; (v) 2D spatial filtering and (vi) amplitude correction to boost deeper reflection and amplitudes. Once completed and wil all GPR 2D profiles having their known spatial position, horizontal time-slices of were generated for each repeat GPR survey using a background removal filter.

2.3 Magnetic susceptibility/conductivity data collection and processing

The Slingram method, in which both the primary field (transmitter coil) as the (receiving coil) move together at a constant separation (see Reynolds, 2011; Thiesson et al, 2011), was used to simultaneously obtain both susceptibility and conductivity measurements with GSSI™ 400 Profiler equipment. Data collection was at *c.* 1-monthly intervals after burial (Table 2). A 2 m x 11 m grid was collected, composed of north-south parallel lines separated every 0.5 m, with sample intervals of 0.5 m and each measurement taking 1 s for consistency. After initial trials and equipment calibration following best practice (see Pringle et al, 2012a; Reynolds, 2011), the vertical component (VMD) and frequencies of 11,000 Hz, 13,000 Hz and 15,000 Hz were chosen to be optimal at the test site.

Once the data was collected onto a hand-held portable logging device and downloaded, data was input into Microsoft Excel and was (i) despiked to eliminate anomalous data outliers before being exported into Generic Mapping Tools (GMT) software to have (ii) respective dataset averages removed and (iii) detrended to remove long wavelength site trends and finally (iv) digital gridded, colour contoured surfaces of both magnetic susceptibilities and bulk ground conductivity to be generated.

2.4 Electrical resistivity data collection and processing

Electrical resistivity surface datasets were acquired in the same 2 m x 11 m survey grid as described in section 2.3. A Geoelectric Abem™ Terrameter was used with a twin probe (dipole-dipole) mobile equipment configuration, with 0.1m long steel mobile probes at 0.5 m spacing and each penetrated 0.05 m into the ground at each sample position. Steel remote probes were at 1 m spacing and placed ~15 m away from the survey area following standard practice (Reynolds, 2011; Clark, 1996). Datasets were collected at approximately monthly intervals (Table 2) and comprised of four east-west parallel lines of 11 m in length, separated every 0.5 m, with sample intervals of 0.25 m along each survey line.

Once the data was collected onto a hand-held portable logging device and downloaded, data was input into Microsoft Excel and was (i) despiked to eliminate anomalous data outliers before being exported into Generic Mapping Tools (GMT) software to have (ii) respective dataset averages removed and (iii) detrended to remove long wavelength site trends and finally (iv) digital gridded, colour contoured surface of electrical resistivity to be generated.

3. Results

3.1. Ground penetrating radar

Selected GPR 250 MHz and 500 MHz 2D profiles (Fig. 4) and time slices (Fig. 5) acquired throughout the survey period are shown (see Fig. 3 for respective profile locations).

The simulated modern clandestine grave with the pig as the murder victim (Pig) was the best detected of all the simulated graves, as a hyperbolic reflection event by both the 250 MHz and 500 MHz and relatively high amplitude anomalies on horizontal time slices throughout the survey period, except for weeks 17 and 21 where there were relatively weaker anomalies present in the respective datasets (Figs. 4 and 5) and were the driest (Fig. 2). The empty control (Cont) graves were imaged as disturbed ground by both frequencies on 2D profiles (Fig. 4) and on horizontal time slices (Fig. 5) during the survey period, although the anomalies on the time slices where of lower amplitude compared to the 'pig' graves.

Both the skeletonized (Skel) and burnt (Burnt) remains locations were able to be imaged throughout the survey period; however, in contrast with the modern simulated graves which had hyperbolic reflection events on 2D profiles, these had characteristic strong horizontal reflections (Fig. 4). Again the weeks 17-21 were weakest in both the 2D profiles (Fig. 4) and horizontal time sclices (Fig. 5) with little differentiation between these and the control graves. The skeletonized remains were better imaged than the skeletonized and burnt remains; however both were more obvious with the 250 MHz compared to the 500 MHz frequency data (*cf.* Figs. 4 and 5). Interestingly the 43 weeks post-burial dataset showed excellent results for both the skeletonized remains and the burnt skeletonized remains (*cf.* Fig. 4) which was the wettest weeks (Fig. 2).

Fig. 4. and new Fig. 5. Position.

3.2 Magnetic Susceptibility

The magnetic susceptibility inphase component results are repeatable between surveys (see Fig. 6); there were clear north-south trending non-target features throughout all surveys. The simulated modern clandestine burials (Pig) had generally high magnetic susceptibilities, with respect to background values, throughout the survey period. The control burial (Control) was not clearly detected throughout the survey period and had variable responses, with respect to background values. Both the simulated historic clandestine graves with skeletonized (Skel) and burnt (Burnt) remains were poorly identified as relatively high magnetic susceptibilities, compared to background values (*cf.* Fig. 6).

Fig. 6. Position.

3.3 Bulk ground Conductivity

During the study the average minimum survey values were 524 ppm and maximum survey values were 283 ppm with a survey dataset average of 224 ppm, once standard de-spiking data processing had been undertaken.

The bulk ground conductivity (quadrature) results were again repeatable, albeit with varying conductivity ranges (Fig. 7), with some north-south trending areas present. The simulated modern clandestine grave (Pig) has generally low conductivities, with respect to background values, except for last dataset (Fig. 7). The control burial (Control) was not clearly detected throughout the survey period. Both the simulated historic clandestine graves with skeletonized (Skel) and burnt (Burnt) remains had mixed results with low and high anomalies present, with respect to background values, and were not clearly identified.

Fig. 7. Position.

3.4 Electrical resistivity

During the study the the minimum average survey values were 421.5 Ω.m and maximum survey values were 1096.1 Ω.m with a survey dataset average of 731.7 Ω.m.

The respective electrical resistivity datasets had similar relative contrasts over the study site throughout the survey period (Fig. 8). Both the simulated modern clandestine grave (Pig) and the control burial (Cont) had consistent low anomalies, with respect to background values, throughout the survey period.

Both the simulated historic clandestine graves with skeletonized (Skel) and burnt (Burnt) remains had relatively high resistive anomalies, with respect to background values, throughout the survey period (Fig. 8). None of the simulated graves could be clearly differentiated from background soil heterogeneities.

Fig. 8. Position.

3.5 Grave soil moisture content

The excavated soil from the simulated clandestine graves were analyzed following standard procedures (Jervis et al., 2009) and found that the top soil moisture content varied between 52% to 66% that correlated to the climate data (Fig. 2). These soil moistures were less than those reported in a rural environment in Colombia (Molina et al. 2015) but almost double to those reported by authors in more temperate climate studies (Jervis et al., 2009).

3.6 Forensic Botany

After four weeks of burial, surface botanical vegetation was observed to be predominantly *brachiaria decumbens* grass between the simulated clandestine graves. After the end of the survey period, Family *Malvaceae* and Species *Petiveria alliacea* vegetation was observed over all graves that are common in these forests (Fig. 9).

Fig. 9. Position.

4. Discussion

Whilst the main clandestine graves typically encountered by forensic search teams in Latin America were discussed in (Molina et al. 2015), this paper has allowed some questions posed by forensic search teams to be addressed and indeed compared to other forensic research and case studies.

The research aims were *firstly to assess whether radar, surface magnetic susceptibility, bulk ground conductivity and electrical resistivity methods could detect the simulated graves*. GPR could identify the simulated modern clandestine grave using both the 250 MHz and 500 MHz frequency antennae, with it being shown as a hyperbolic reflection event in 2D profiles (Fig. 4). In contrast, the other simulated targets were imaged as strong horizontal reflections on 2D profiles. Horizontal time-slice data showed relative high amplitude anomalies over all the buried targets, with respect to background values, throughout the survey period, with relatively dryer survey periods having lower amplitude anomalies were present in the respective datasets. Magnetic susceptibility and bulk ground conductivity results were generally poor and further research is suggested with this technique as other authors have begun to find (e.g. see Linford, 2004; Pringle et al., 2015b). Electrical resistivity surveys showed relatively low anomalies around the simulated modern clandestine grave and high anomalies for the simulated historic simulated graves, with respect to background values, but it would be difficult to justify that these anomalies were due to the buried targets and not due to background soil and/or moisture variations.

The second paper aim was to determine if there was an optimal time for surveying post-burial. GPR 2D profiles with both the 250 MHz and 500 MHz antenna frequencies could detect the simulated burials, except for weeks 17 and 21 which were generally dryer (see Fig. 2 and Table 2). This contrasted with the (Molina et al., 2015) study in a rural depositional environment in Colombia which had poorly imaged hyperbolic reflection events over the same survey periods post-burial with 250 MHz frequency GPR datasets. There did not seem to be an optimum post-burial time period to undertake magnetic susceptibility, bulk ground conductivity and electrical resistivity over the mornitoing period study as these results were generally poor (*c.f.* Figs. 6-7).

The third paper aim was to compare this study results to other studies, particularly other Latin American control burial studies. Although this has been partially answered in the first two aims, clearly there are similarities with other controlled studies in particular with the (Molina et al. 2015) study in a rural depositional environment in Colombia. Both showed good detection results with relatively low frequency (250 MHz) GPR 2D profiles over similar monitoring periods. Controlled studies in both North America (Shultz and Martin, 2011; Schultz and Martin, 2012) and Europe (Pringle et al., 2008; Pringle et al., 2012c) has shown GPR to be an effective detection technique for clandestine and historic burials. Magnetic susceptibility is beginning to be used for forensic search applications (Pringle et al. 2015b; Pringle et al., 2012b), but here was not shown to be promising. Electrical resistivity surveys were also not very useful at detecting burials, in contrast to the European control studies (Pringle et al., 2012c), for reasons that are presently unclear. Bulk ground conductivity has not been successful here, as a UK study has also shown (Pringle et al., 2008), although it was used successfully for a New Zealand missing person case study (Nobes, 2000). Observed surface botanical results were also different to that observed in the (Molina et al. 2015) study, expected when in different depositional environments; these are summarized in Fig. 10. Lastly the simulated burials in this paper were the typical 0.5 m bgl simulated studies conducted elsewhere (e.g. Schultz and Martin, 2011; Schultz and Martin, 2012; Pringle et al., 2008); so perhaps some results could be compared to burials in graveyards where burial depths similar (see Hansen et al., 2014).

5. Conclusions

Simulated clandestine graves commonly encountered in Latin America have been created on a control test site in a rainforest in Villavicencio, Colombia. These have included using partialy clothed pig cadavers as simulated modern clandestine graves, and simulated historic graves using donated skeletonised human remains and beheaded and burnt donated skeletonised human remains.

Sequential monitoring of the simulated clandestine graves over 11 months (0-43 weeks) by both the 250 MHz and 500 MHz frequency GPR on 2D profiles, evidenced that the simulated modern clandestine burials could be imaged throughout the survey period on both 2D profiles and horizontal time slices. The rest of the burials and control graves were imaged as disturbed features. Magnetic susceptibility, bulk ground conductivity and electrical resistivity results were generally poor at detecting the simulated targets. .

Soil moisture contents were over 50% and similar to those reported elsewhere in Latin America. Secondary succession surface vegetation variations documented where different to those reported in rural depositional environments in Latin America.

Further work should continue to monitor these burials to several years to give forensic investigators databases to compare their results to and perhaps see if there is an observed temporal changes in target detection. Control studies using simulated mass burials should also be undertaked as this is also sadly a common scenario encountered in South America. Other soil types and depositional environments should also be investigated in other control studies. Finally these techniques should also be used in real forensic search scenarios to investigate their effectiveness.

6. Acknowledgements

The authors would like to thank the Universidad Nacional de Colombia for the support to undertake the study. The Granja Experimental Barcelona that belongs to the Universidad de Los Llanos is thanked for providing the study site. GeoSense are acknowledged for loaning of the GPR equipment and Sandox for loan of the EMI equipment. The Instituto Geografico Agustin Codazzi is acknowledged for providing soil analysis and the Estación Unillanos-IDEAM is thanked for providing meteorological datasets. A Santander fellowship in collaboration with Keele University funded a short research exchange programme for the lead author.

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8. Figure Captions:

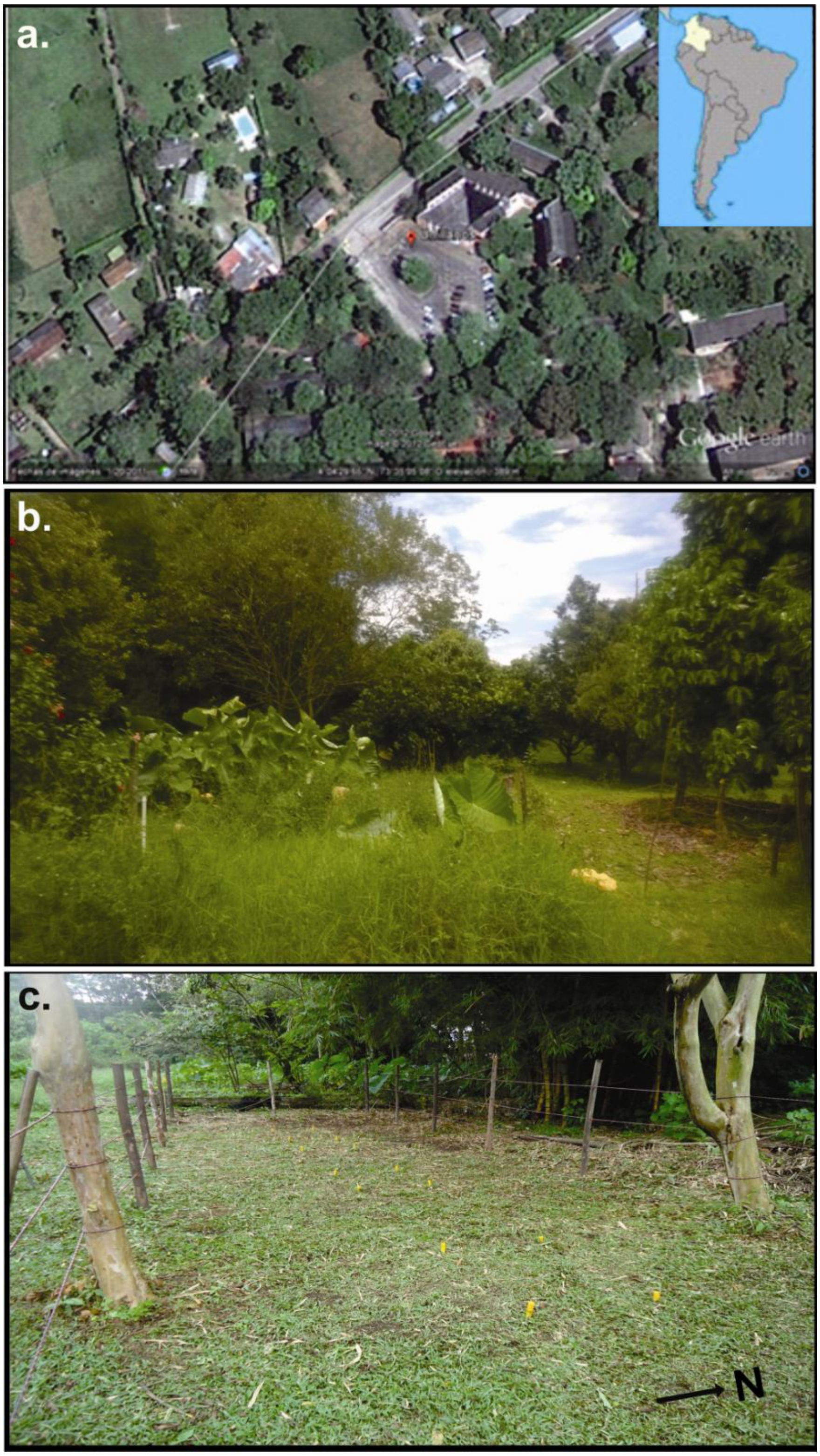

Fig.1. (a) Aerial photograph at the University of Los Llanos, Colombia with location (inset). (b) General study site photograph of Experimental Farm Barcelona. (c) Fenced test site with orange stakes denoting grave position.

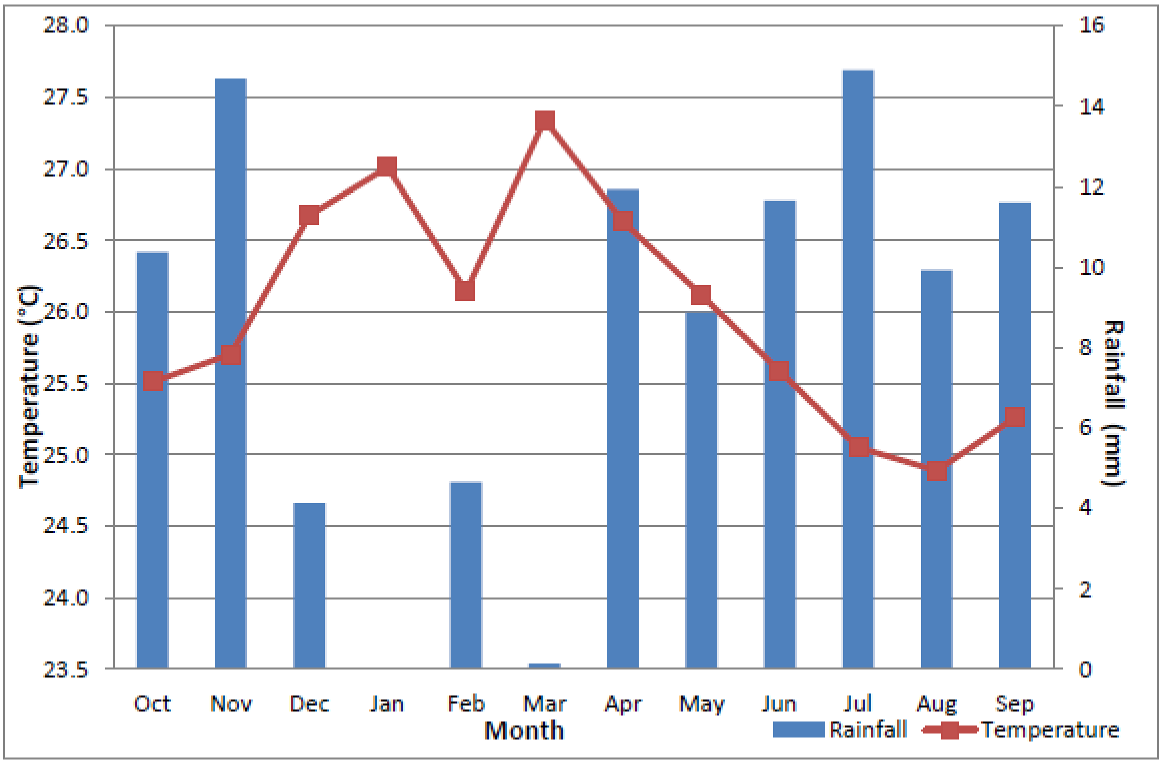

Fig. 2. Summary of monthly study site statistics of total rainfall (bars) and average temperature (line) data over the study period.

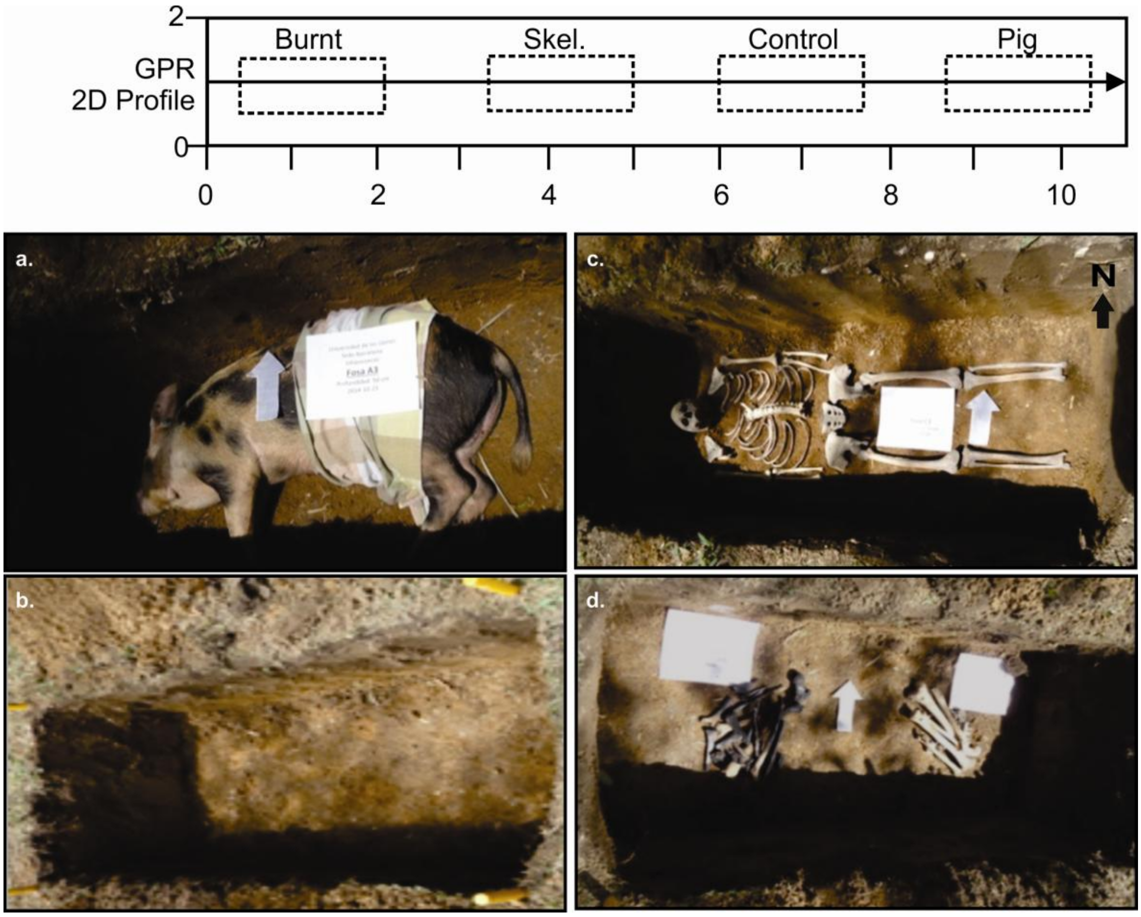

Fig. 3. (a) Plan-view of control test site showing positions of four simulated clandestine graves (annotated) buried at 0.5 m below ground level (bgl) and GPR 2D profile location and orientation. (b) Simulated clandestine grave with partially clothed domestic pig cadaver. (c) simulated clandestine empty grave for control. (d) Simulated historic clandestine grave with skeletonized human remains. (e) simulated historic clandestine grave with beheaded and burnt skeletonized human remains.

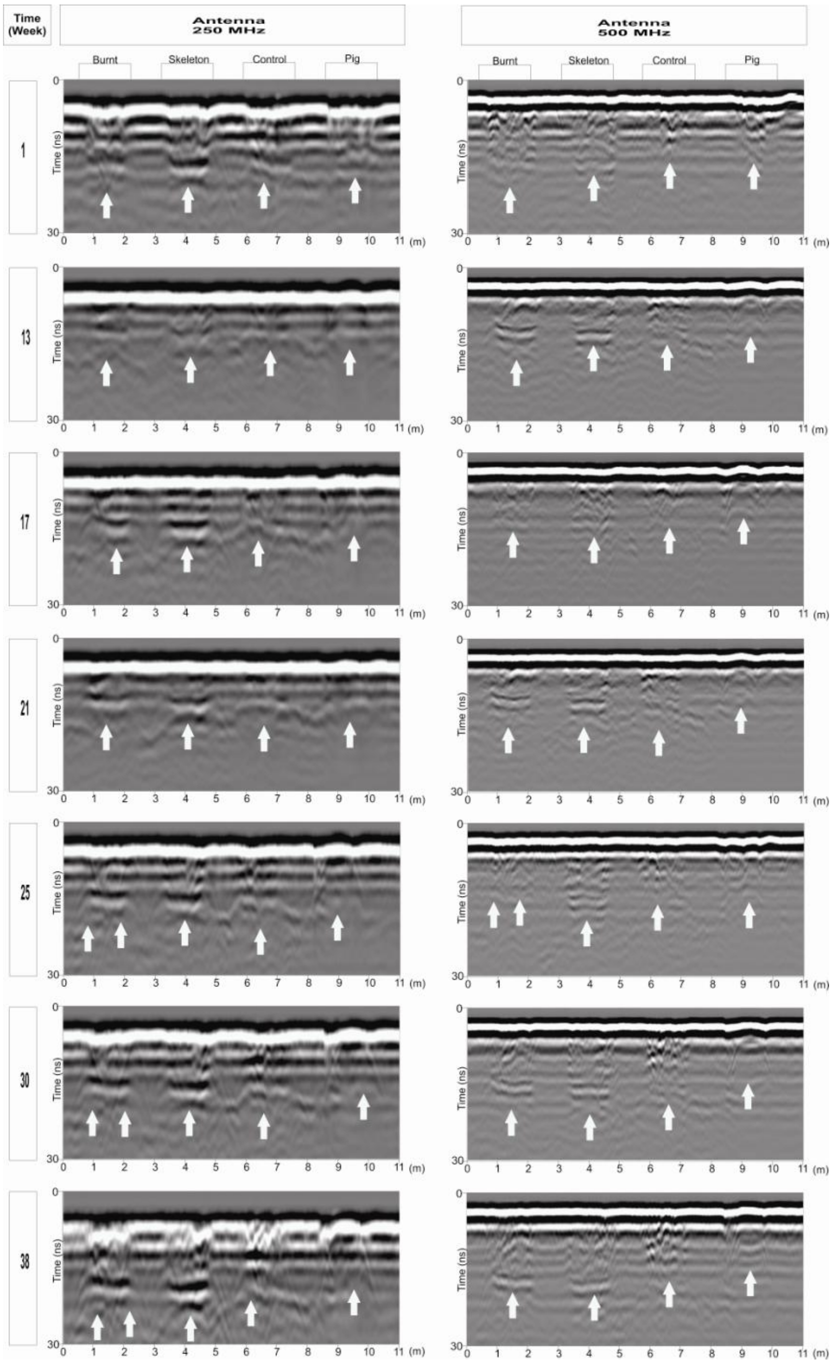

Fig. 4. Sequential selected GPR 250 MHz and 500 MHz frequency 2D profiles taken over the simulated clandestine grave sites, showing 1 week, 13 weeks, 17 weeks, 21 weeks, 25 weeks, 30 weeks, 38 weeks and 43 weeks post-burial data respectively. Buried simulated named grave positions (see Table 1 for detail) and any resulting half hyperbolic reflection events (arrows) are marked (see text for details and Fig. 3a for location).

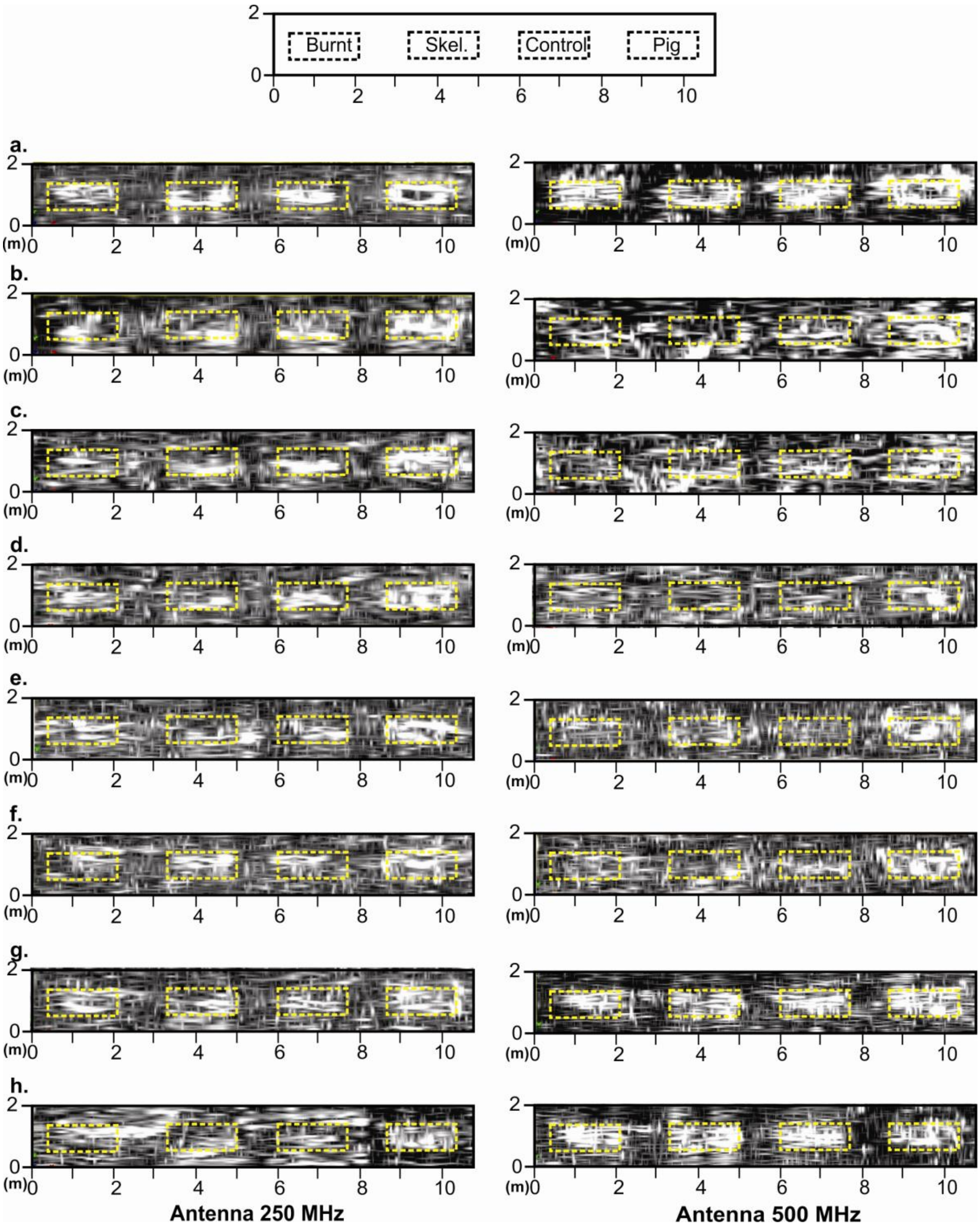

Fig. 5. Sequential selected GPR 250 MHz and 500 MHz frequency horizontal time slices taken over the simulated clandestine grave sites, showing a.1 week, b. 13 weeks, c. 17 weeks, d. 21 weeks, e. 25 weeks, f. 30 weeks, g. 38 weeks and h. 43 weeks post-burial data respectively. Buried simulated named grave positions (see Table 1 for detail) shown at top are marked (see text for details).

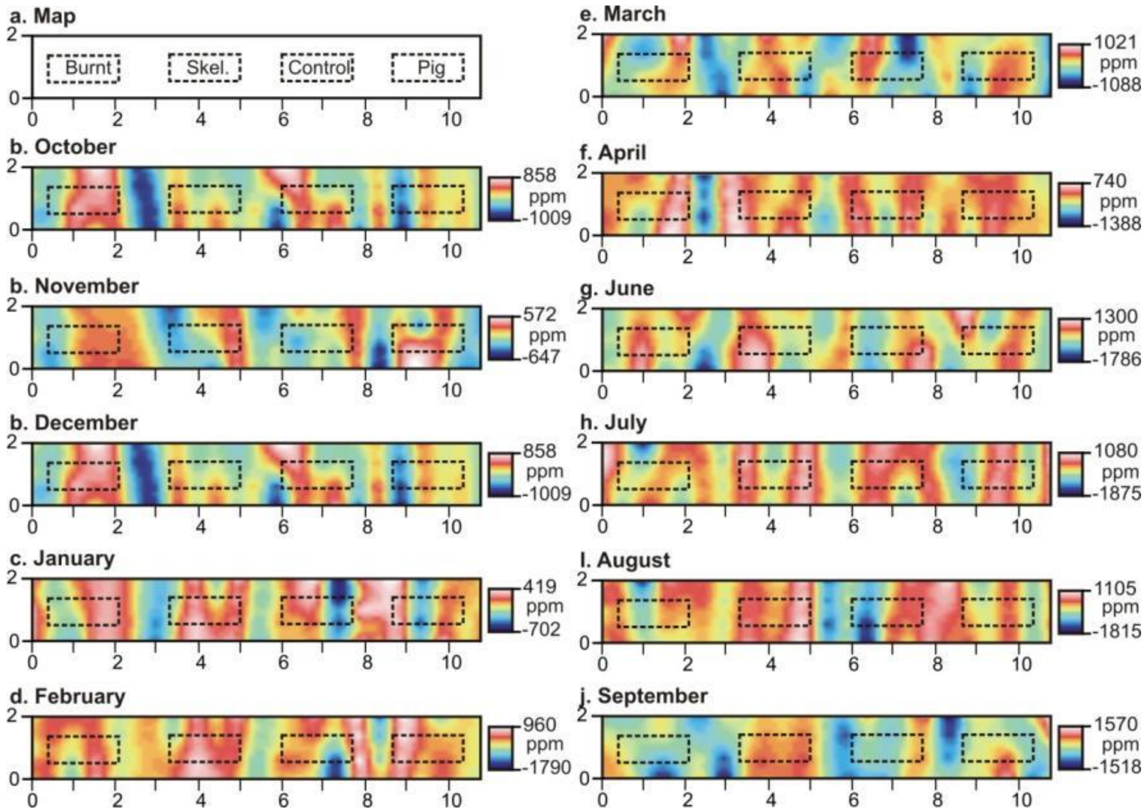

Fig. 6. Sequential magnetic susceptibility (mapview) processed datasets over the study period (see respective keys). Buried simulated grave positions shown at top and dotted lines throughout (see text for details).

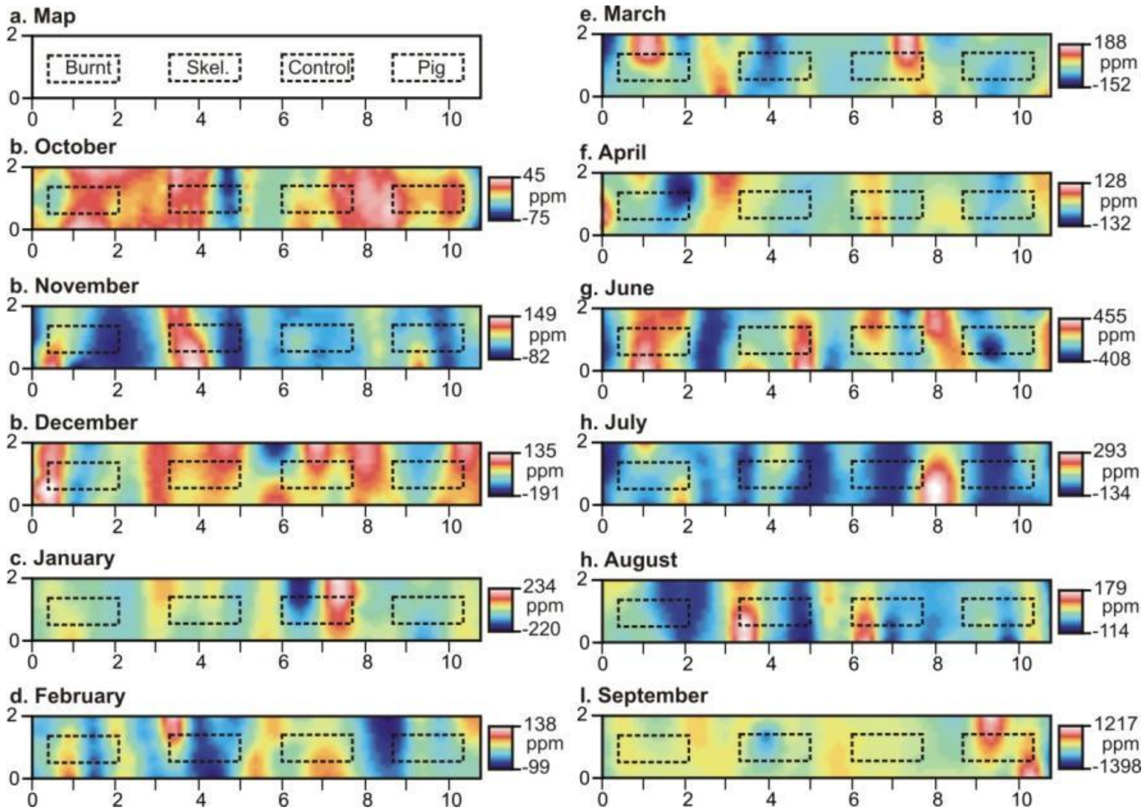

Fig. 7. Sequential conductivity (mapview) processed datasets over the study period (see respective keys). Buried simulated grave positions shown at top and dotted lines throughout (see text for details).

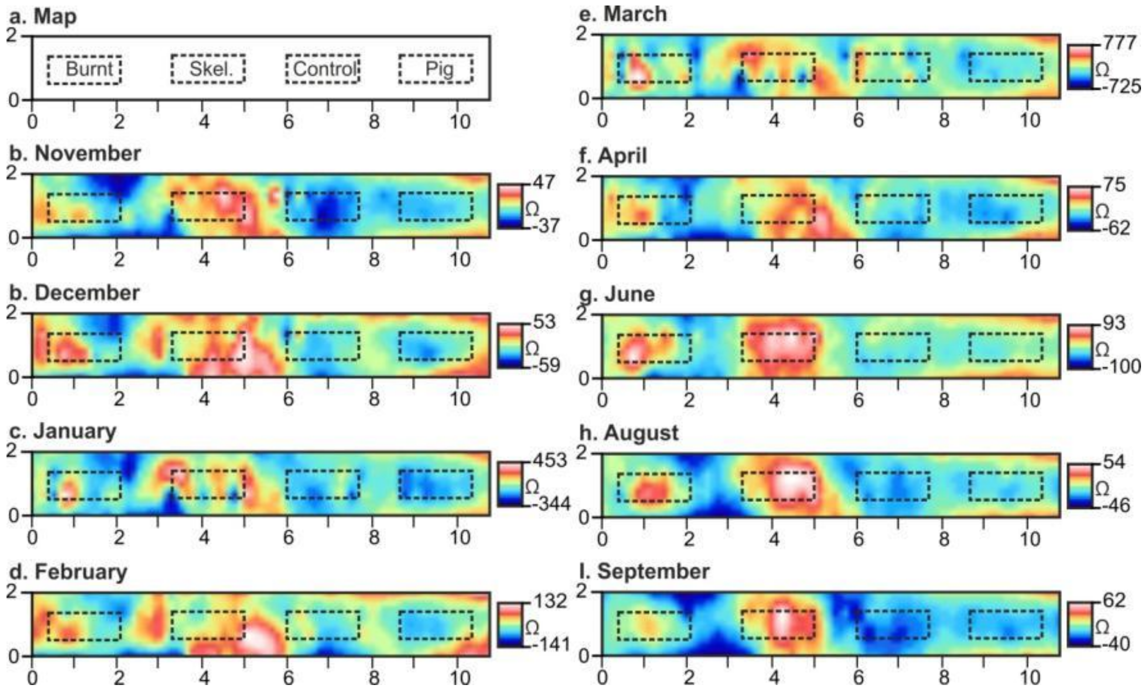

Fig. 8. Sequential electrical resistivity (mapview) processed datasets over the study period (see respective keys). Buried simulated grave positions shown at top and dotted lines throughout (see text for details).

Fig. 9. Sequential photographs of surface botany over simulated clandestine graves. (a) No vegetation after 5 weeks of burial. (b) *Brachiaria decumbens* grass growing between simulated graves over graves after 17 weeks of burial. (c) *Malvaceae* and *Petiveria alliacea* growing over simulated clandestine graves after 34 weeks of burial.

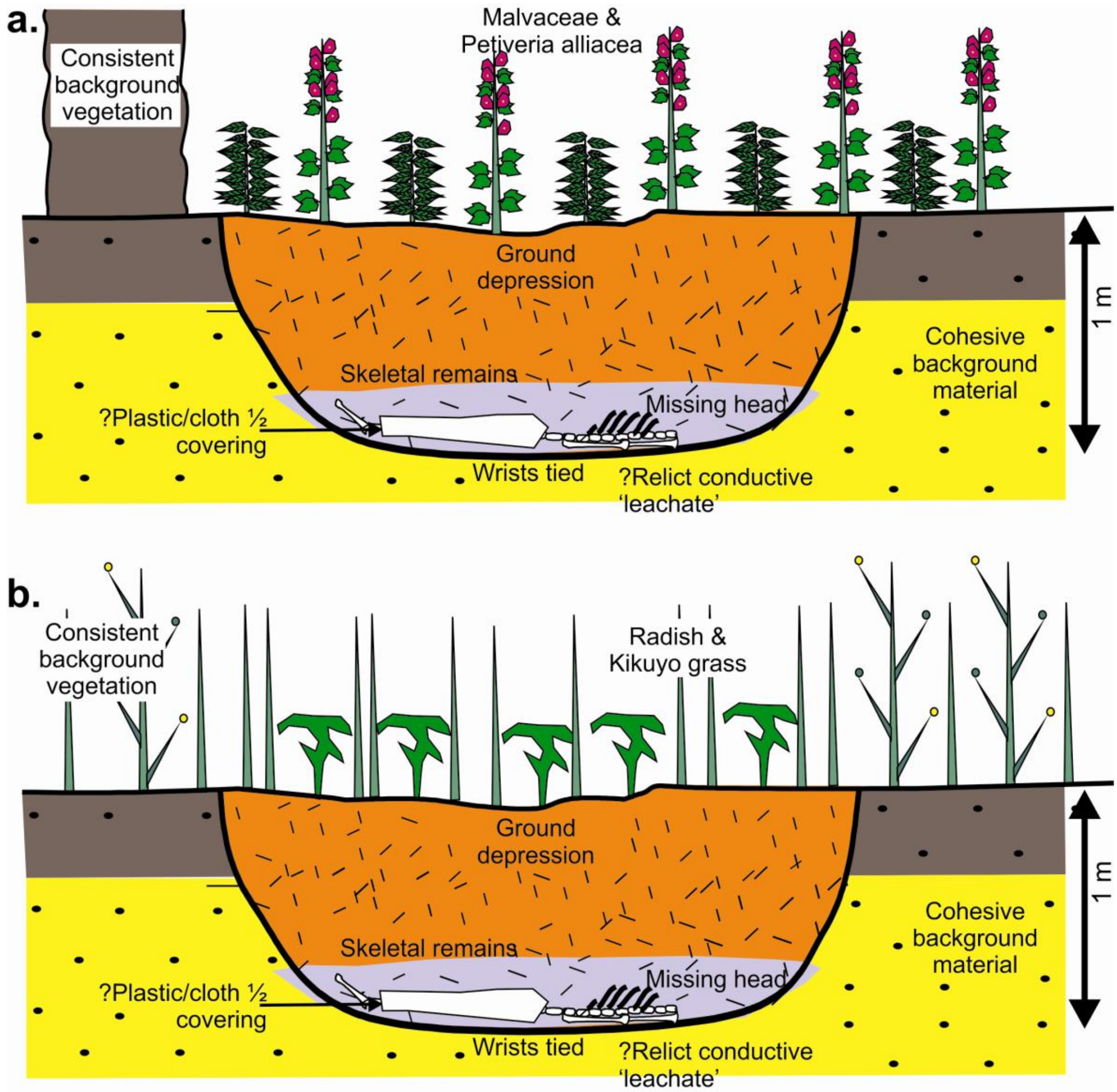

Fig. 10. Schematic annotated diagrams of typical clandestine grave encountered in Latin America in (a) tropical rainforest shown in this paper and (b) semi-rural environment (modified from Molina et al. 2015).

Tables & captions

Grave name	Dimensions	Contents	Description	Justification
Pig	1.7 m x 0.7 m x 0.5 m bgl	70 kg domestic pig carcass freshly dispatched	Bottom half wrapped in cloth	Represents partially clothed cadaver; a common scenario
Cont	1.7 m x 0.7 m x 0.5 m bgl	None	Dug and refilled	Acted as control
Skel	1.7 m x 0.7 m x 0.5 m bgl	Skeletonised human remains with 6 mm x 9 mm and 4 mm x 38 mm bullet casings	Skeleton placed in dorsal extended position	Common homicide scenario
Burnt	1.7 m x 0.7 m x 0.5 m bgl	Skeletonised human remains with 6 mm x 9 mm and 4 mm x 38 mm bullet casings	Bones laid out anatomically correct	Common homicide scenario

Table 1. Details of simulated clandestine graves emplaced at the test site with dimensions, contents and justifications all given (see Fig. 3 for location). Modified from Molina et al. (2015).

Survey date	Survey day after burial*	Accumulated degree day (ADD)
24/10/2014	1	26.9
19/11/2014	27	720.9
18/12/2014	56	1441.9
14/01/2015	83	2145.1
11/02/2015	111	2877.4
11/03/2015	139	3614.9
08/04/2015	167	4361.2
13/05/2015	202	5273,8
10/06/2015	230	5990,0
09/07/2015	259	6717.5
12/08/2015	293	7563.8
10/09/2015	322	8295.8

Table 2. Summary of geophysical data collected during this study. *Burial date was 23th October 2014. Accumulated degree day calculated from average daily temperature information (see text for details) but note that this is not relevant or skeletonised remains as these are not *in situ*.